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A Multi-Agent Approach to the Simulation of Robotized Manufacturing Systems

K Foit, A Gwiazda, W Banaś

Silesian University of Technology, Faculty of Mechanical Engineering, Institute of Engineering Processes Automation and Integrated Manufacturing Systems,
Konarskiego 18A, 44-100 Gliwice, Poland

E-mail: krzysztof.foit@polsl.pl

Abstract. The recent years of eventful industry development, brought many competing products, addressed to the same market segment. The shortening of a development cycle became a necessity if the company would like to be competitive. Because of switching to the Intelligent Manufacturing model the industry search for new scheduling algorithms, while the traditional ones do not meet the current requirements. The agent-based approach has been considered by many researchers as an important way of evolution of modern manufacturing systems. Due to the properties of the multi-agent systems, this methodology is very helpful during creation of the model of production system, allowing depicting both processing and informational part. The complexity of such approach makes the analysis impossible without the computer assistance. Computer simulation still uses a mathematical model to recreate a real situation, but nowadays the 2D or 3D virtual environments or even virtual reality have been used for realistic illustration of the considered systems. This paper will focus on robotized manufacturing system and will present the one of possible approaches to the simulation of such systems. The selection of multi-agent approach is motivated by the flexibility of this solution that offers the modularity, robustness and autonomy.

1. Introduction

The fast development of information technology and growing availability of online shopping have broadened the quantity of goods at affordable prices that are within reach of the average customer. The global market enforces competitiveness that in turn causes shorter lifetime of products, faster speed of updates (new versions) and the necessity to answer the diversified demands of customers. The process of manufacturing becomes more demand-oriented than product-oriented in order to survive on the market. This induces the readiness for fast changes in the assortment, while maintaining the quality and reasonable costs of single piece and for this reason the modern industry follows the vision of flexible, multiproduct manufacturing. Using the advanced technologies, equipment and the new methods of managements imply completely different methods of production planning and processes modelling [1,2]. This also apply to the methods of machines diagnostic and evaluation of energy consumption [7,8] It should be also mentioned, that On the forefront of contemporary methods of modelling and simulation are computer-based techniques that use object-based models [3,4]. This is the older approach, but still used by many simulation software, when there is no need of enabling some sophisticated processes, like self-organization, evolution of a system etc. On the other hand many scientists turn towards the agent-based models also in the case of manufacturing system modelling [5,6]. In general, the agent could be regarded as “intelligent object” – it means that the



object contains certain amount of information about itself and the environment in which he acts along with having implemented some procedures that allow him to interact with the other objects and the environment.

The paper focuses on the use of multi-agent approach to the modelling of robotized manufacturing system. It will show the main assumptions connected with the agent-based method and depict the principles of modelling, but no simulation results will be presented. The aim is to show universal approach to the problem of agent-based simulation.

2. Overview of agent-based modelling principles

The agent-based modelling is firmly embedded in the principles of multi-agents systems, known in the artificial intelligence field. The agent could be represented by the physical object (eg. robot, machine tool) or by virtual entity, an abstract that often have the form of computer program code, data or mathematical equations. Depending on their roles, the agents can be proactive (goal-directed, do modifications in the environment) or reactive (reacting for changes in the environment). Wooldridge [10] states that the agent should have two subsystems that are responsive for proactive and reactive behaviour. Such set forms of so-called hybrid agent, where the both kinds of behaviour should be properly balanced.

Other important properties of agents are communication and interaction. The interaction between agents can be direct, using a communication channel or indirect, when the agents operate on the same resource [11]. The type of communication depends on the architecture of agents. In a small set of autonomous agents, the communication is realized by direct “talk” of one agent to another. The large sets of agents, based on hierarchy or federation architectures, communicate through the other agents. In the hierarchy architecture, lower lever agents send messages to the higher level (master) agent that process and alternatively redirect the information to the right destination. The agents that are inside the federation structure communicate by means of special agents like brokers, mediators or facilitators [12].

Referring to the ability of agents to cooperate, there is no explicit manner to realize this task. The simplest way is to define a set of rules for every agent, which could be considered in relation to the other agents and the environment. The rules can be very primitive, using classic *if...then* syntax or decision tree form. More sophisticated approaches include fuzzy logic, game theory [13,14], biological models or even some paradigms from physics, like classical mechanics [14].

2.1. Agent-based models of manufacturing systems

The agent-based approach to the manufacturing system is readily used by researchers around the world. It is based on the assumption that every resource is an agent (machines, operators, robots, storages, buffers etc.) [15]. The multi-agent models of manufacturing systems use several specialized methodologies and architectures, for example:

- AARIA (*Autonomous Agents at Rock Island Arsenal*) [16] – the main principle is that manufacturing resources (machines, people, parts etc.) are autonomous agent; the communication between agents is set on messages that are broadcasted to agents subscribing the specific content (subject-based addressing),
- CORTES [17] – uses functional decomposition and solves the scheduling problems on two levels: resource reservation and activity planning; uses so-called texture measures to direct the computation conducted by agents
- CAMPS (*Case-based Multiagent Planning/Scheduling*) [18] – in this system agents try to form coalitions, which may dynamically change in order to achieve a proper goal; agents coordinate their actions by handling inner (intra-agent) and outer (inter-agent) constraints.

It is worth to mention about another method described by Sousa and Ramos [19], where the authors proposed the architecture of scheduling system based on two types of holons: one for representing the tasks and another for representing resources. On the other hand, Shen [15] claims that the holon is a

special type of agent, so the mentioned method could be concerned from the agent-based modelling point of view.

As a consequence of elaborating of agent-based methods, there are also the implementations of such theory in practice. The biggest market, where the agent-based systems are implemented, is the IT market: intelligent internet search engines, applications for mobile devices, cars etc. that uses software agents to act in synergic manner. Slowly, but consequently grows up the field of simulation and agent-oriented languages – as an example it is worth to mention the JADE system, which is based on JAVA programming language, NetLogo that is a system influenced by the Logo programming language, AnyLogic, which can use the stock and flow diagrams, state charts, action charts and process flowchart in order to develop the simulation – eventually the InsightMaker, which is the web-based application. The example of specialized, agent-based system is the MAST [20], which is dedicated for simulation of material handling systems used in manufacturing processes.

3. The problem of self-organization of the production flow in terms of agent-based model

Let's consider a very simple robotic cell that consists of one robot, two machines, input and output storages and one temporary buffer (figure 1). Assuming that every object is represented by agent, there will be six agents that will cooperate to achieve a goal. The goal is to prepare a crafted article from the input material.

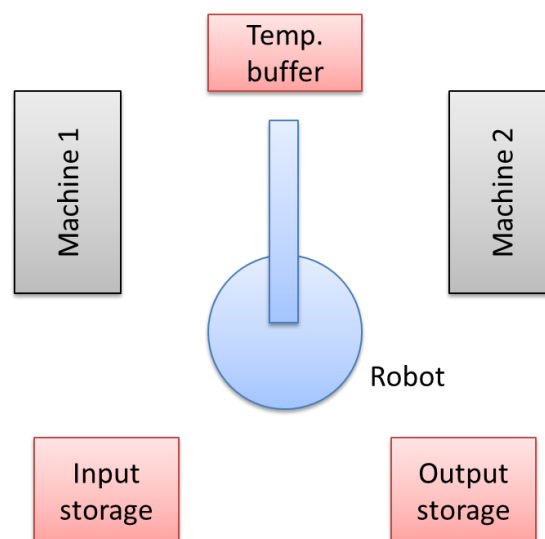


Figure 1. The configuration of considered robotic cell

After the rough evaluation of the problem it is necessary to determine the informational part of agents. Except the physical parameters like the capacity of storages, times of machining and object transportation, the other useful variables will be the flags that determine the status of individual agents. The flag may have form of integer number, like e.g. number of items in a storage, or Boolean value, when it defines status like for example *busy* or *empty*. In the simplest model, in order to act, the agent needs the set of rules (triggers) and methods. The methods are the “bodily functions” of agent, while the rules are the “intelligence”. The considered case does not require complex AI functions, because the work of every agent is highly repeatable and the workflow could be regulated by parameters, except the situation when one or more agent has a failure. The list of selected parameters, flags, and methods for the individual agents that form the cell are summarized in table 1.

The presented cell could work in two manners. The first one is the serial use of machines, where the new material is not introduced until the process of previous item is not ended. Such process is not effective, so there is other possibility that assumes the use of both machines in the same time. After

finishing the process on the *Machine 1*, the part is moved to the *Machine 2*. The robot picks up the new material from *Input storage* and moves it to the *Machine 1*. The machines are used more efficiently, but this approach requires precise timing of each stage of work.

Table 1. The list of selected parameters and methods of the agents forming the considered cell

Agent	Parameters & flags	Methods
Input storage	capacity: <i>integer</i>	ask (<i>who, for what</i>)
	no_of_items: <i>integer</i>	broadcast (<i>message</i>)
	empty: <i>Boolean</i>	
Output storage	capacity: <i>integer</i>	ask (<i>who, for what</i>)
	no_of_items: <i>integer</i>	broadcast (<i>message</i>)
	empty: <i>Boolean</i>	
Machine 1	process_params: <i>array</i> ,	ask (<i>who, for what</i>)
	busy: <i>Boolean</i> ,	broadcast (<i>message</i>)
	failure: <i>Boolean</i>	chuck (<i>open/close</i>)
	chuck_on: <i>Boolean</i>	door (<i>open/close</i>)
Machine 2	process_params: <i>array</i> ,	ask (<i>who, for what</i>)
	busy: <i>Boolean</i> ,	broadcast (<i>message</i>)
	failure: <i>Boolean</i>	chuck (<i>open/close</i>)
	chuck_on: <i>Boolean</i>	door (<i>open/close</i>)
Temporary buffer	capacity: <i>integer</i>	ask (<i>who, for what</i>)
	no_of_items: <i>integer</i>	broadcast (<i>message</i>)
	empty: <i>Boolean</i>	
Robot	busy: <i>Boolean</i> ,	ask (<i>who, for what</i>)
	gripper_on: <i>Boolean</i>	broadcast (<i>message</i>)
	failure: <i>Boolean</i>	gripper (<i>open/close</i>)
		move_to (<i>point</i>)

The parameters and methods given in table 1 do not require any special comments – only the *ask* and *broadcast* methods need to be explained more precisely. The *ask* method is used by one agent to address the other while certain action is required. On the other hand, the *broadcast* method could be used to inform all the agents about some event, for example when the agent restored itself after the failure.

The whole process cannot be properly conducted without the assistance of the robot, while only this agent may act in different places. Although there is assumption that every agent can communicate with each other (using the *ask* or *broadcast* methods), the robot is the most important agent in the cell. This suggests rather the hierarchy architecture, not the autonomous one, but it is worth to pay attention to the fact that self-organization requires the contribution of all agents. Considering the process where both machines are fully used, the robot must know which machine needs attention. The machine agent may ask for it using *ask* method. In some situations, the robot must know about the status of the machine. Proper timing ensures that it is rarely necessary. In some conditions, there may be situation when the robot should move the part from *Machine 1* to *Machine 2*, but *Machine 2* is still working and *Robot* agent has not the information about readiness of machine. The robot may ask for the estimated

time to finish and on this basis may decide what to do next – which subroutine should be selected. The other example of self-organization may be the change of timing because of conditions inside or outside the cell.

The above considerations apply to the model of multi-agent system, which has been prepared in order to simulate it in the virtual environment. In fact, the same rules may apply to the real manufacturing system, where the real machines could be represented by software agents implemented in control systems, which may communicate through the industrial network.

4. Conclusions

Nowadays customers have at their disposal information tools that enable them to search for a product on worldwide market. Such situation imposes the strong competition between manufacturers around the world. They focus on more efficient production, but simultaneously try to keep the same quality of their products. The use of the same machines for manufacturing different assortment induces the searching for the new technologies and modern methods of production management. The multi-agent approach gives the new possibilities of controlling the flow of products, using the main property of agent-based systems, which is the ability of self-organization. Although most of such methods are in research stage, the new simulation tools are developed. These applications are capable to use the multi-agent formalism to run the virtual process and use all of the advantages of mentioned method. Therefore it is important to focus on the principles of agents' behaviour in order to efficiently use the simulation environment. This paper has discussed some important issues like organization of multi-agent environment, communication between agents and eventually the problem of self-organization in relation to the manufacturing process. Quite important is also the question of relationship between the multi-agent systems and the others, similar organizational forms of manufacturing processes models. It should be noted, that contemporary researches more frequently centre of mixed models and attempt to elaborate efficient methods of modelling.

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